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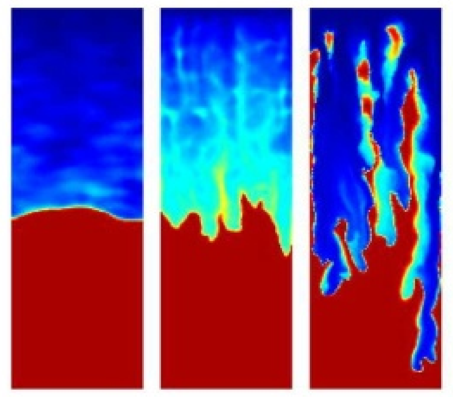
Publication date:
2014

Document Version
Publisher's PDF, also known as Version of record



DFG Research unit MUSIS

Heat and Water Transport in Soils and across the Soil-Atmosphere Interface: Comparison of Model Concepts.

Jan Vanderborght[1], Kathleen Smits[2], Klaus Mosthaf[3], Thomas Fetzer[4], Ebrahim Shahraeeni[1], and Rainer Helmig[4].

[1]Agrosphere Institute (IBG-3) Forschungszentrum Jülich, Germany, [2]Center for the Experimental Study of Subsurface Environmental Processes (CESEP), Colorado School of Mines, USA, [3]Dept. of Environmental Engineering, Technical University of Denmark, [4]Dept. of Hydromechanics and Modelling of Hydrosystems, University of Stuttgart, Germany.

Introduction

Evaporation from the soil surface represents a water flow and transport process in a porous medium that is coupled with a free air flow and with heat fluxes in the system. We give an overview of different model concepts that are used to describe this process.

Concepts

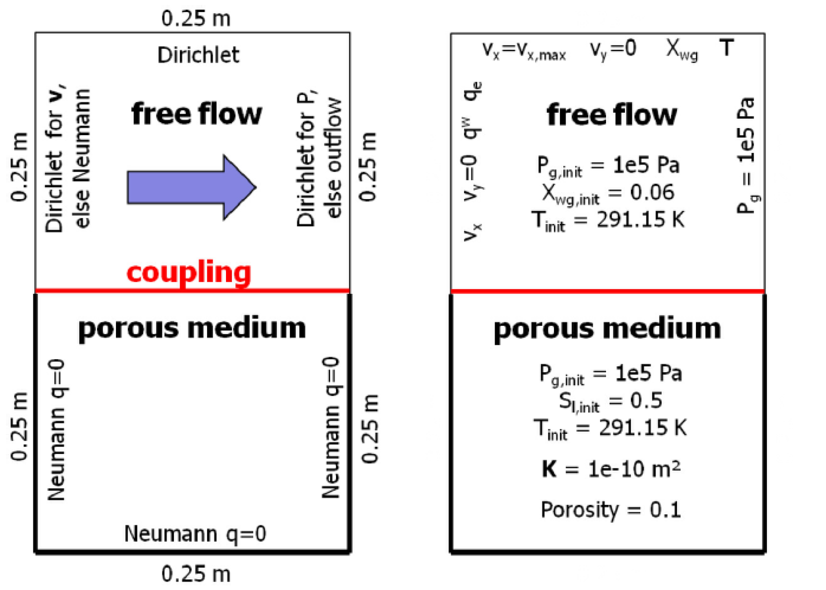
General Assumptions:

- Thermal equilibrium: temperature of all phases is equal
- Chemical equilibrium: Kelvin equation relates vapor pressure in gas phase with capillary pressure of liquid phase.
- Mechanical equilibrium.

Overview of concepts:

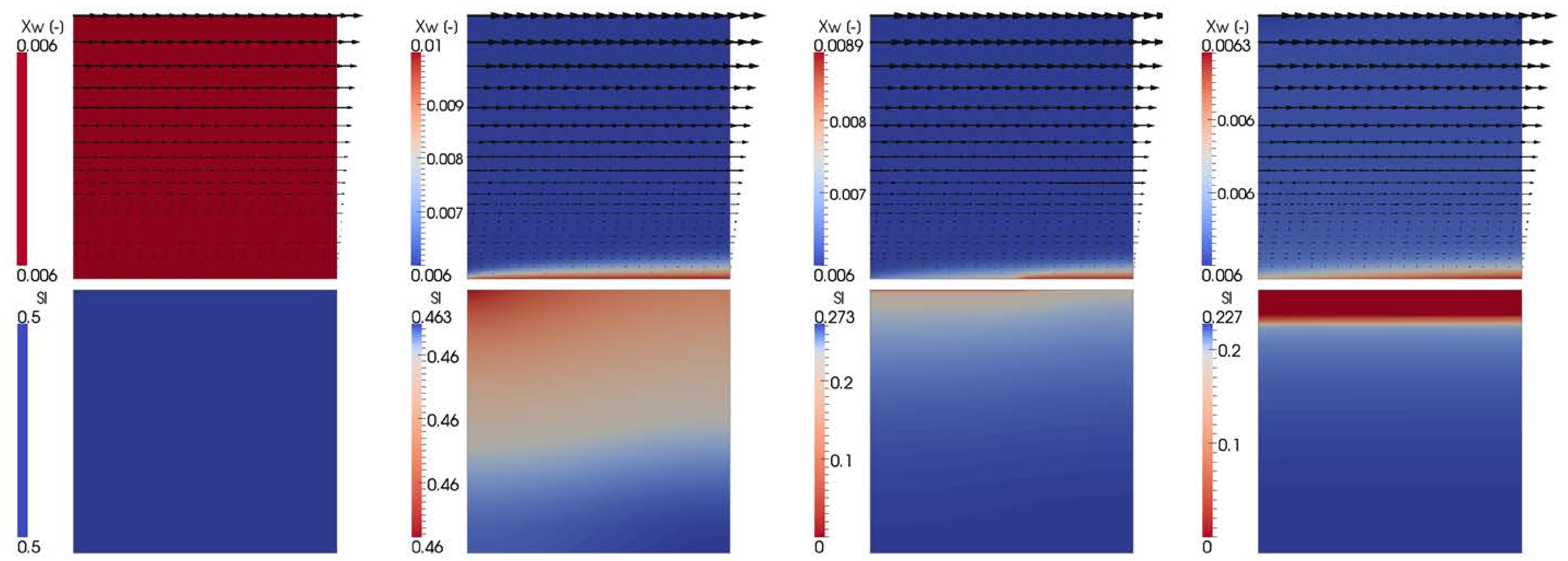
	2D 2-phase 2-component	1D 1.5-phase 1-component	1D 1-phase 1-component (isothermal Richards equation with mixed BC)
Free flow	Turbulent flow Mass/heat transfer in turbulent flow	Logarithmic vertical wind profiles 1D mass transfer in turbulent air flow	Logarithmic vertical wind profiles 1D mass transfer in turbulent air flow
Coupling	Continuity in component mass fluxes, heat fluxes, and normal forces (Beavers-Joseph for tangential flow at boundary),	Continuity in water mass and heat fluxes.	Either saturated vapor presssure → water flux is calculated from surface energy balance, or prescribed pressure head.
Porous medium	Flow of liquid and gas phases (2 phases) Transport of heat in solid, liquid and air phases. Transport of water and dry air components in both phases	Flow of liquid phase (1 phase) Transport of heat in solid, liquid and air phases. Transport of water in both phases (only vapor diffusion in gas phase)	Flow of liquid phase (1 phase) Transport of water only in liquid phase
	Dumu[x] (Mosthaf et al., 2011)	Hydrus (Saito et al., 2006)	Hydrus (Simunek et al., 2008)

2-D Models: Lateral variations in fluxes and state variables from/on heterogeneous surfaces



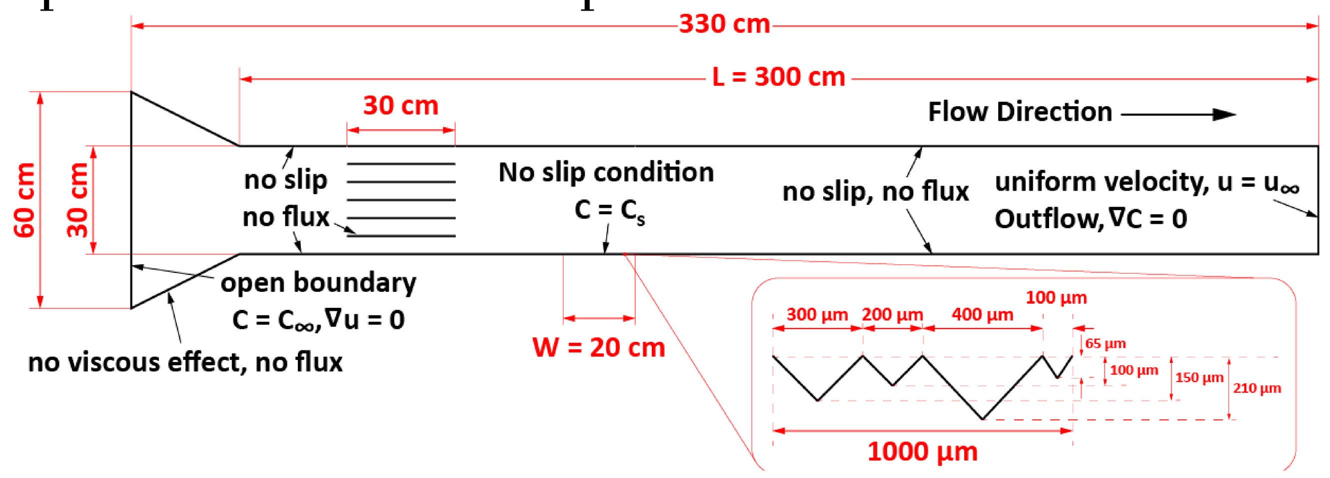
(a) Model setup. (b) Initial and boundary condi-

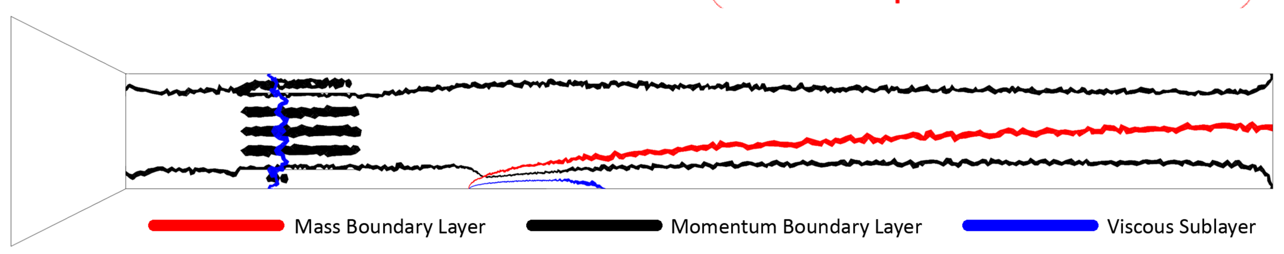
Figure 1: Effect of lateral variations in vapor content in the free flow due to varying boundary layer thickness on drying. Left: simulation setup, below: time series of simulated water contents in the porous medium. (Mosthaf et al., 2011)



t = 0 d t = 1 d t = 12.5 d t = 33 d

Effect of lateral variations in vapor content in the free flow on evaporation rates from wet patches different size.





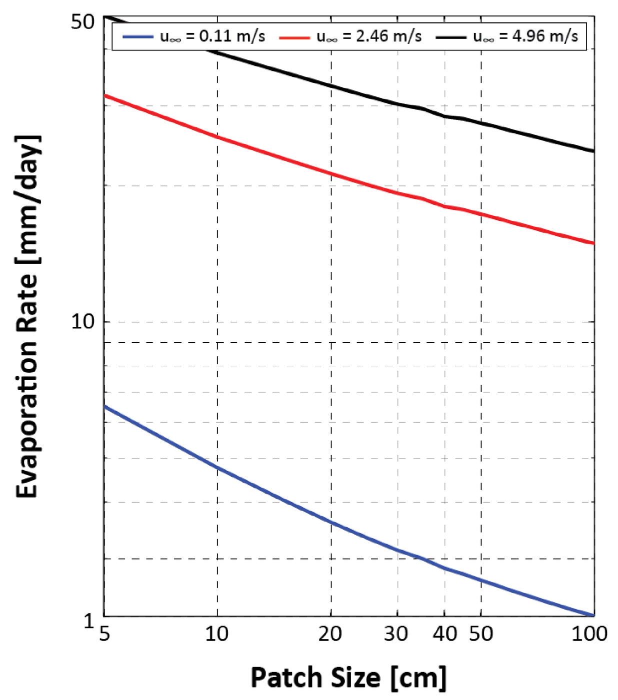
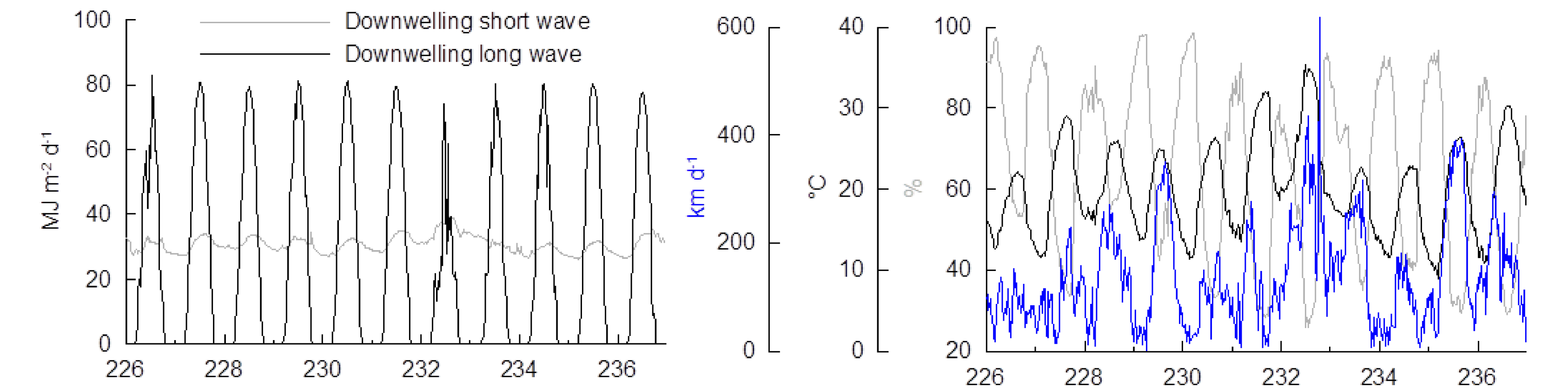
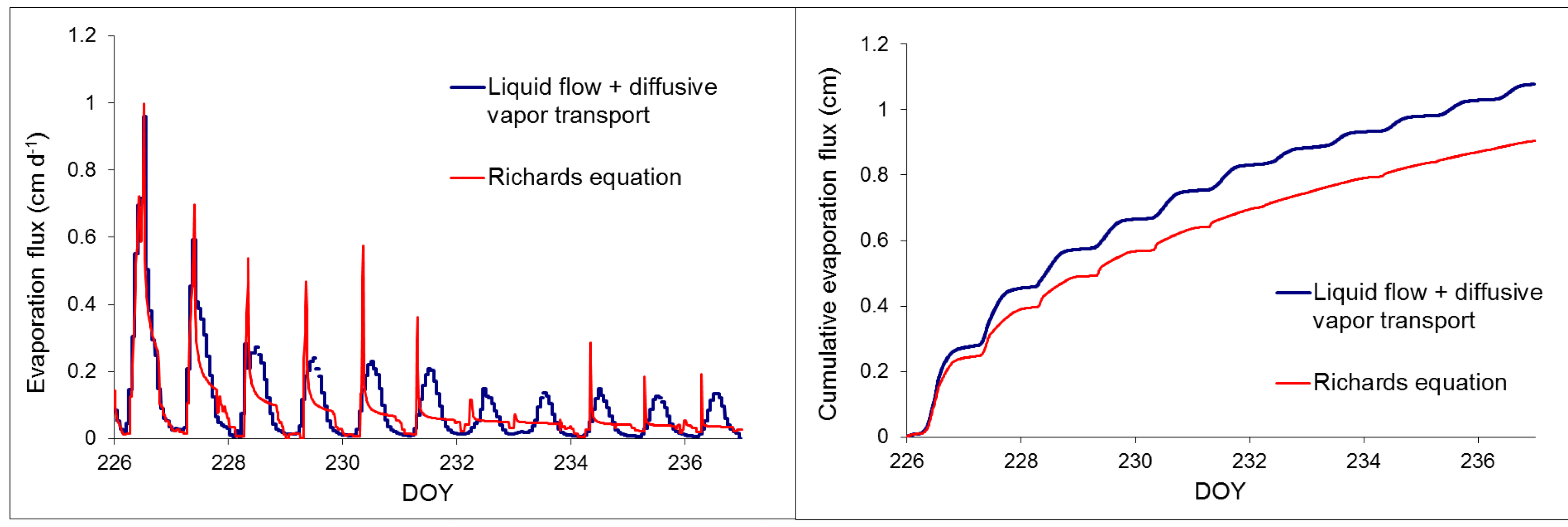


Figure 2: Simulation set up (top), simulated boundary layers (middle), evaporation rate for different patch sizes and wind speed (bottom). Only free flow is simulated and vapor concentration, Cs, at the free flow-porous medium is given as constant boundary condition in this example.

1-D Models: Transient atmospheric boundary conditions

Figure 3: Atmospheric boundary cond. (top), Evaporation fluxes and cumulative evap. (bottom)





Diurnal dynamics of evaporation fluxes is not reproduced by Richards equation, but, cumulative evaporation losses over a longer time are. Why? (1) Rewrite mass balance in terms of a diffusion equation with diffusivity D_w, (2) Use Boltzmann transform, (3) cumulative evaporation increases with $t^{0.5}$ and proportionality factor is desorptivity S_{evap}, (4) S_{evap} is an average of D_w over θ → mostly determined by liquid phase diffusivity.

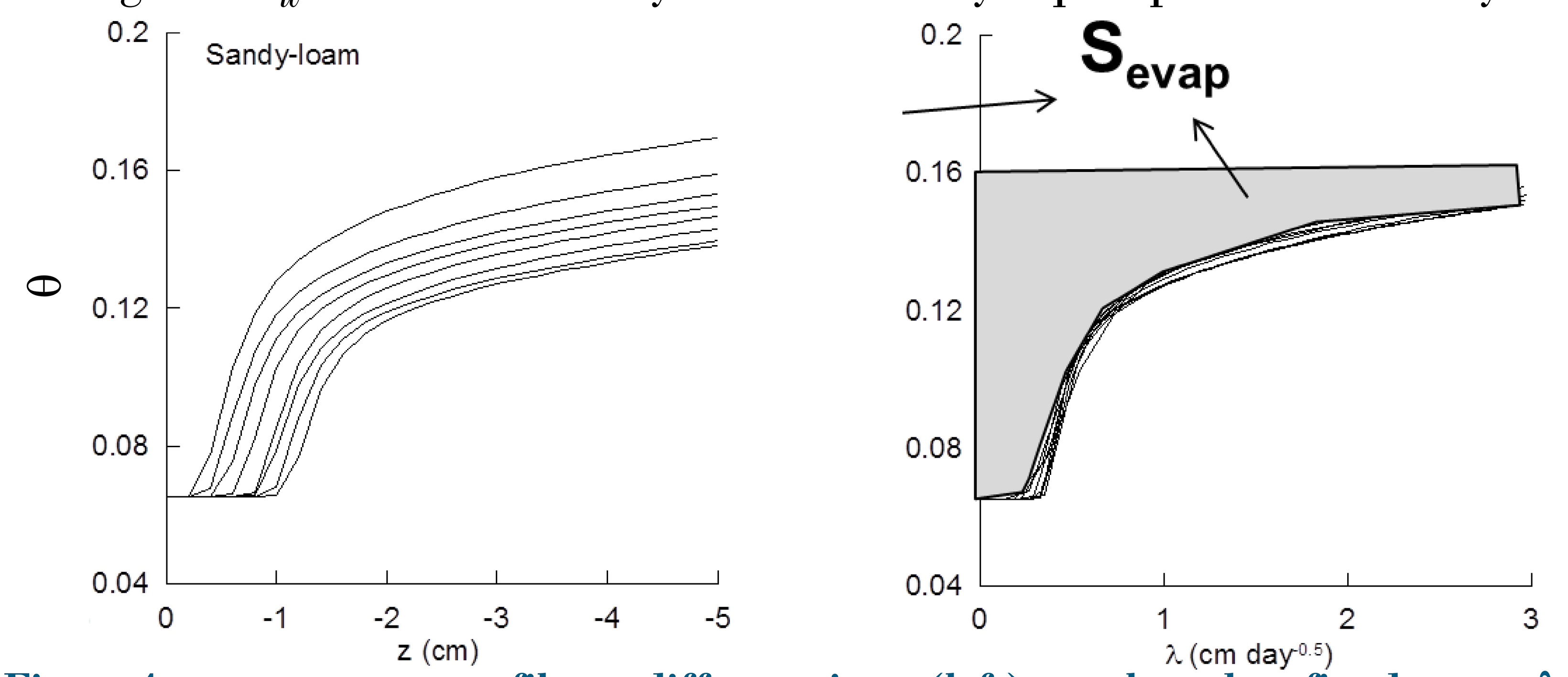


Figure 4: water content profiles at different times (left), overlap when fitted versus λ (right)+ graphical representation of S_{evap}

$$(1)\quad \frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}\left(D_w(\theta)\frac{\partial\theta}{\partial z}\right)+\frac{\partial K(\theta)}{\partial z}\qquad D_w=\left(K_{l,\psi}+\frac{gM_w\rho_{vs}H_r}{\rho_l RT}\mathbf{D}^w_{g,eff}(S_g)\right)\frac{\partial\psi}{\partial\theta}$$

$$(2)\quad \lambda=\frac{|z|}{\sqrt{t}}\qquad -\frac{\lambda}{2}\frac{d\theta}{d\lambda}=\frac{d}{d\lambda}\left(D_w\frac{d\theta}{d\lambda}\right)\qquad (3)\quad E\mathrm{cum}=S\mathrm{evap}\sqrt{t}$$

$$(4)\quad S^2_{\mathrm{evap}}=\frac{8}{3}(\theta_i-\theta_{\mathrm{sur}})^2\int_0^1(1-\Theta)D_w(\Theta)\,d\Theta\qquad \Theta=\frac{\theta-\theta_{\mathrm{sur}}}{\theta_i-\theta_{\mathrm{sur}}}$$

Acknowledgments

This work is funded by the research Unit MUSIS of the German Science Foundation.

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